**VILNIUS GEDIMINAS TECHNICAL UNIVERSITY**

FACULTY OF ELECTRONICS

DEPARTMENT OF TELECOMMUNICATION ENGINEERING

**Jaime Pérez Bautista**

# DEPLOYMENT AND INSTALLATION OF A WIRELESS BROADBAND AREA NETWORK IN AN URBAN AREA

Final bachelor‘s work

Vilnius, 2011

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**Defended on January 28th, 2011, Vilnius, Lithuania**

*Thanks to everyone who made this possible:*
*To my parents, who supported me from the very beginning.*
*To my brother, simply for everything.*
*To my friends, who always trusted in me.*
*To my coordinators, who had their door always open for my questions.*
*And to VGTU, for offering me this amazing opportunity of studying abroad.*

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# INDEX

# 1. INTRODUCTION

This project's purpose is studying and developing a Wi-Fi net in an urban area in order to offer service to all people living in that area.

Even in the United States of America, there is a proposal to the Congress treating the broadband access to the Internet as a right of the citizens. This should be an example of how important is Internet in this world we are living in.

Nowadays, Wi-Fi is one of the best ways to access to the Internet, not just because of the comfort, but for the reach, speed and simplicity it provides to users. It is also one of the most reliable wireless systems. Besides, it is probably the most known kind of access, because now not just computers get connected to the Internet. PDAs, mobile phones and even televisions can get access to the Internet.

The aim is making a full installation of a wireless Local Area Network. For it, we will study the options we have and decide which one is better for the urban area we will try to give coverage. We will decide that basing on the coverage, the simplicity, the implementation, the ease for the users and of course the environmental protection and the price of the project.

Once we had decided what to do, it will be important how to do it. We will decide what equipment are we going to use and how many stations, having in mind that too many stations increase the price but too few stations decrease the service quality.

We will give coverage to single users, not to big enterprises or governmental ones (for example: hospitals, police stations, etc.). That is for two reasons. The main one is that those kind of users usually need a very strong data protection, and a public LAN is never as secure as a private one. The second reason is the huge amount of users in so little area that it represents. We will make a study of population density in order to offer a good service to the area.

In order to do this, we have chosen a representative municipality, which can be considered as an urban area due to its amount of citizens, landscape and the jobs of the people living there.

Through this work, we would like to create the consciousness that installing a free WLAN for public use is possible, and would mean a big step into 21st century's technology and needs.

In today's world, the invention of the Internet can only be equaled to the invention of the wheel. Both of them changed the way of communicating and trading. Both of them meant a complete change in life.

# 2. WI-FI STANDARD

## 802.11

802.11 is a standard made by the Institute of Electronic and Electric Engineers (IEEE). This protocol defines the two lower OSI architecture level use (physical and data link layers) specifying their working way in a Wireless Local Area Network (WLAN). [1]

Moreover than preserving all the characteristics from a wired network, wireless networks offer mainly four advantages:

- Mobility: users of a wireless network can move inside the coverage range of the elements which provide access to the network.
- Simplicity and ease of installation: all problems caused by wiring a net get annulled.
- Installation flexibility: having no wires provides the opportunity of reaching places where wires cannot offer service.
- Charge reduction: the economic issue is one of the best advantages of this standard. The installation and maintenance costs are lower. Besides, in environments where there is need of frequent moves, additions and changes, long-term benefits are even higher.

The mechanism of access specified by standard 802.11 is CSMA/CA, and the modulation may be DSSS (Direct Sequence Spread Spectrum) or FHSS (Frequency Hopping Spread Spectrum).

The allowed speed goes from 1 Mbps to 2 Mbps, and it works in the 2'4 Ghz frequency band (2,412 Ghz – 2,484 Ghz). This band presents much interference because it is a public-access band, and it is used by wireless phones and microwave ovens, as for many other devices.

Improves have been implemented, creating this way new substandards.

## 802.11b

802.11b has a maximum raw data rate of 11 Mbit/s and uses the same CSMA/CA media access method defined in the original standard. Due to the CSMA/CA protocol overhead, in practice the maximum 802.11b throughput that an application can achieve is about 5.9 Mbit/s using TCP and 7.1 Mbit/s using UDP. [2]

802.11b products appeared on the market in mid-1999, since 802.11b is a direct extension of the DSSS (Direct-sequence spread spectrum) modulation technique defined in the original standard. Technically, the 802.11b standard uses Complementary code keying (CCK) as its modulation technique. The dramatic increase in throughput of 802.11b (compared to the original standard) along with simultaneous substantial price reductions led to the rapid acceptance of 802.11b as the definitive wireless LAN technology.

802.11b devices suffer interference from other products operating in the 2.4 GHz band. Devices operating in the 2.4 GHz range include: microwave ovens, Bluetooth devices, baby monitors and cordless telephones. Interference issues and user density problems within the 2.4 GHz band have become a major concern and frustration for users.

## 802.11g

802.11g emerges as an improvement of 802.11b standard in 2003. The operation band is 2.4 Ghz, but thanks to OFDM modulation it can offer up to 54 Mbps speed. [3]

Wi-Fi (Wireless Fidelity) is the enterprise which certificates that the devices cataloged as 802.11g fulfill the specified characteristics and can work properly.

As it has been commented before, the 2.4 Ghz band includes the frequencies between 2412 Mhz and 2848 Mhz. The next table shows the relation between channel identifiers and main frequencies established in 802.11g substandard.

| CHANNEL IDENTIFIER | MAIN FREQUENCIES (MHZ) |
|---|---|
| 1 | 2412 |
| 2 | 2417 |
| 3 | 2422 |
| 4 | 2427 |
| 5 | 2432 |
| 6 | 2437 |
| 7 | 2442 |
| 8 | 2447 |
| 9 | 2452 |
| 10 | 2457 |
| 11 | 2462 |
| 12 | 2467 |
| 13 | 2472 |
| 14 | 2484 |

**Table 1. 802.11g channels and frequencies**

The bandwidth of the signal, which is 22 Mhz, is bigger than the gap between two consecutive channels (5 Mhz). For that, it is necessary a minimum gap of 5 channels in order to avoid interferences between adjacent cells.

In this thesis, 802.11g will be the implemented standard.

## 802.11n

IEEE 802.11n is an amendment to IEEE 802.11 and builds on previous 802.11 standards by adding multiple-input multiple-output (MIMO) and 40 MHz channels to the physical layer, and frame aggregation to the MAC layer. [4]

MIMO is a technology which uses multiple antennas to coherently resolve more information than possible using a single antenna. One way it provides this is through Spatial Division Multiplexing (SDM). SDM spatially multiplexes multiple independent data streams, transferred simultaneously within one spectral channel of bandwidth. MIMO SDM can significantly increase data throughput as the number of resolved spatial data streams is increased. Each spatial stream requires a discrete antenna at both the transmitter and the receiver. In addition, MIMO technology requires a separate radio frequency chain and analog-to-digital converter for each MIMO antenna which translates to higher implementation costs compared to non-MIMO systems.

Channels operating at 40 MHz are another feature incorporated into 802.11n which doubles the channel width from 20 MHz in previous 802.11 PHYs to transmit data. This allows for a doubling of the PHY data rate over a single 20 MHz channel. It can be enabled in the 5 GHz mode, or within the 2.4 GHz if there is knowledge that it will not interfere with any other 802.11 or non-802.11 (such as Bluetooth) system using those same frequencies.

Coupling MIMO architecture with wider bandwidth channels offers increased physical transfer rate over 802.11a (5 GHz) and 802.11g (2.4 GHz).

Data encoding

The transmitter and receiver use precoding and postcoding techniques, respectively, to achieve the capacity of a MIMO link. Precoding includes spatial beamforming and spatial coding, where spatial beamforming improves the received signal quality at the decoding stage. Spatial coding can increase data throughput via spatial multiplexing and increase range by exploiting the spatial diversity, through techniques such as Alamouti coding.

## 802.16

Protocol 802.16 is a standard created in 2002 by the IEEE. This protocol is about the specification for Wireless Metropolitan Area Networks (WMAN).

802.16 works in frequencies between 10 Ghz and 66 Ghz, and the speed it can reach oscillate between 32 and 134 Mbps, depending on the distance to the receptor, with 28 Mhz channels.

The modulation is adaptive, which means that, in function to the link conditions, the system changes the modulation type (64-QAM, 18-QAM or QPSK) to obtain better results. The system works just under direct visibility and with fixed stations. [5]

WIMAX /Worldwide Interoperability for Microwave Access) is the brand that certifies a product is accordant to the wireless access standards IEEE 802.16.

# NET TOPOLOGIES

The net topology represents the arrangement of the links connecting a network's nodes. The distance between nodes, the transmission rate or physical interconnections do not belong to the topology, although they can be affected by it.

There exist several topologies, but here there will be described just those possible in a wireless network. [6]

## Star topology

In this kind of topology every node connects to a central concentrator, so that all data passes through the concentrator before reaching its destiny.

The most important advantage of star topology is that a peripheral node's fail does not influence the behavior of the rest of the network. However, if the central node fails, the whole network could fail.

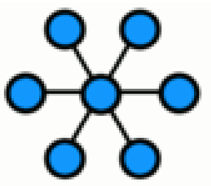

**Figure 1.Star topology**

## In-line topology

In-line topology is a joint of nodes connected one by one, forming a point to point link. The inconvenient it presents is that, if a link fails, there will be several nodes disconnected from the network.

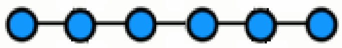

**Figure 2. In-line topology**

### Tree topology

Tree topology is a collection of networks with star topology sorted in hierarchy. If a link connecting a leaf node fails, this gets isolated. The big problems appear when a link connecting an intermediate node fails, because the whole section stays isolated from the network.

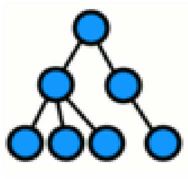

**Figure 3. Tree topology**

The Internet Service Providers (ISPs) use this topology.

### Mesh topology

Every node is connected to one or more nodes, so the messages can reach their destiny in different ways. If there exists a direct link between every node, we talk about a complete meshing. [7]

**Figure 4. Incomplete and complete mesh topology**

The mesh topology presents a lot of advantages, such as reliability and stability.

## OPERATION MODES

The operation mode of a network is how two stations in that network communicate.

802.11 standard defines two kinds of operation modes in wireless networks: ad-hoc and infrastructure. [8] [9]

## Ad-hoc mode

Ad-hoc mode, or so called peer-to-peer, allows the clients of a wireless network to communicate between them directly, without the need of a central access point, In case of a node failure, it does not matter which one, because all devices in the network have the same level or importance.

In an Ad-hoc network the efficiency is lower as the number of nodes increase. Besides, every client has to configure his wireless adapter in “Ad-hoc” mode and use the same SSID (Service Set Identifier) and number of channel of the network.

In IEEE 802.11 networks this mode is called IBSS ( Independent Basic Service Set).

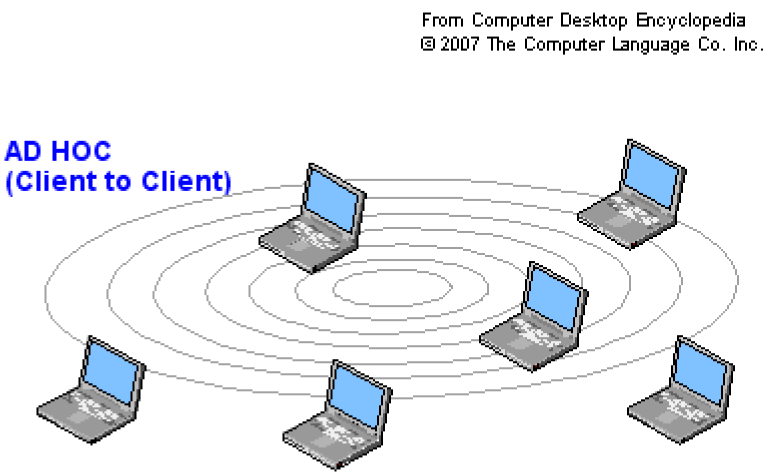


**Figure 5. Ad-hoc mode**

## Infrastructure mode

A network using Infrastructure mode does have a central element. All clients in the network have to be connected to this coordination device, because to communicate with another client the information has to pass through there.

To interconnect many access points and wireless clients, all of them have to be configured with the same SSID. The number of channel can be the same in every access point, although it is recommendable to difference them to ensure the maximum network capacity.

In IEEE 802.11 the Infrastructure mode is known as BSS (Basic Service Set) or as Master and Slave.

Apart from the operation modes already explained, in the communication between two stations it is important to decide the transmission mode. Half-duplex mode is defined as a bidirectional communication but the information sent is not simultaneous. However, in full-duplex the information is much more efficient.

It is also necessary to bear in mind whether the communication is point-to-point or point-to-multipoint. In the first one the information exchange is made between two stations. In the second one, one station communicates with more than one.

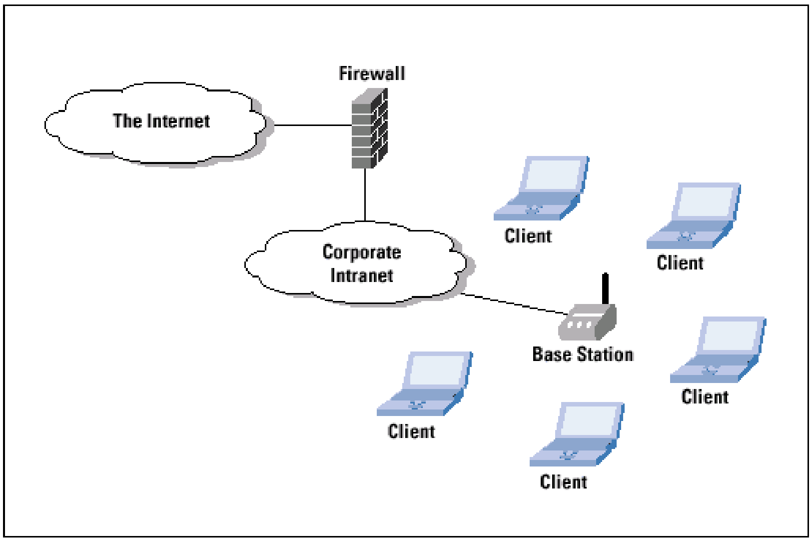


**Figure 6. Infrastructure mode**

# ANTENNAS

An antenna is a device able to transmit and receive radio waves. It is also defined as the adaptation element between guided waves, transmitted by conductors or guides, and waves who propagate in free space. [10]

### Antenna Parameters

To characterize an antenna we should define the next parameters:

- **Radiation diagram**

The radiation diagram is the graphic representation of the radiation characteristics of an antenna in function of the angular direction.

- **Directivity**

The directivity of an antenna is defined as the power density an actual antenna radiates in the direction of its strongest emission, relative to the power density radiated by an ideal isotropic radiator antenna radiating the same amount of total power.

$$D = \max\left(\frac{\text{Radiated power density}\,(\theta,\phi)}{\text{Total radiated power}/\,(4\pi)}\right)$$

- **Gain**

Antenna gain relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions (isotropically) and has no losses.

$$Gain = 4\pi\left(\frac{\text{Radiation Intensity}}{\text{Antenna Input Power}}\right)$$

- **Polarization**

The electromagnetic polarization is defined as the geometric figure that plots the extreme of the electric field vector to a certain distance of the antenna, when time varies. This parameter can be linear, circular or elliptic (circular and elliptic can be right-handed or left-handed).

**Type of antennas**

There exist different types of antennas, classified by their radiation diagram.

- **Isotropic antenna**

It radiates uniformly in all directions over a sphere centered on the source. It is a reference antenna with which other antennas are compared.

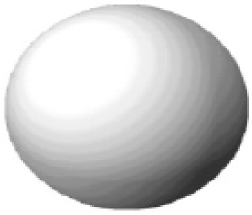

**Figure 7. Isotropic antenna radiation**

- **Omnidirectional antenna**

It is an antenna system which radiates power uniformly in one plane with a directive pattern shape in a perpendicular plane. This pattern is often described as "donut shaped". Omnidirectional antenna can be used to link multiple directional antennas in outdoor point-to-multipoint communication systems. [11]

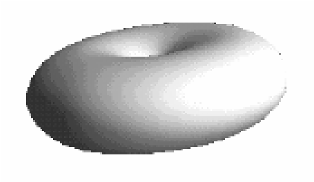

**Figure 8. Omnidirectional antenna radiation**

- **Directional antenna**

It is an antenna which radiates greater power in one or more directions allowing for increased performance on transmit and receive and reduced interference from unwanted sources. It is used mainly in point-to-point links.

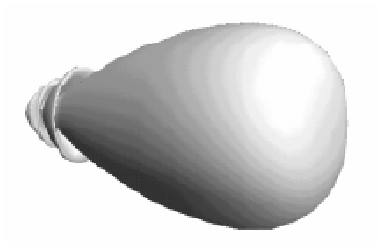

**Figure 9. Directional antenna radiation**

# 3. BAIONA'S CURRENT SITUATION

This chapter is a small introduction to the population of study in order to develop a wireless network. First of all, the geographic situation is presented. Afterwards it is exposed the current Internet situation in Baiona.

## GEOGRAPHIC SITUATION

Baiona is one of the historical municipalities in Pontevedra, one of the four provinces in which Galicia is divided, situated at the north-west of Spain.

The inhabitants are grouped in five parishes: de Baíña (Santa Mariña), Bayona (Santa María de Fóra), Baredo (Santa María), Belesar (San Lourenzo) y Sabarís (Santa Cristina da Ramallosa). [12]

- **Longitude:** 5º 70' 0" and 5º 12' 3" W. from Madrid's Meridian.
- **Latitude:** 42º 2' 40" y 42º 7' 40" N.
- **Minimum height:** 0 m (sea level).
- **Maximum height:** 632 m (Alto de A Groba).
- **Surface:** 34,7 km2.
- **Population:** 11.337 inhabitants (2004 census).


**Figure 10. Baiona's situation in Spain**


**Figure 11. Baiona**

# HISTORY

Baiona's foundation is attributed to Diomedes of Etolia, son of Tui's founder. When the romans invaded the Iberian Peninsula in the 2nd century B.C., they also tried to invade Baiona, avoided by Viriato. One century later, Julio Cesar arranged here his army to expel the herminios from Cies islands.

1201 is a key year in its history, when Alfonso IX from Leon gives to the old Erizana the name of Baiona and grants it privileges for maritime commerce. This way, it was detached from Oia's monastery and started its race to become one of the most important coast villas in Galicia.

Because its strategic value it was attacked in 14th Century by Portuguese and English. These conflicts will ruin it. In 1425 it gets impulse again when Juan II decided that Baiona and A Coruña would be the only docks in Galicia able to import and export merchandise.

In that century, Baiona was scenario of the feudal fights in Galicia. But its glorious time arrived at the end of the century, when the "Pinta" arrived to Baiona's harbor, converting it in the first place in Europe where the existence of America is known. In 1497 the Catholic Kings grant the villa several privileges and order the population living into Monte Boi's fortress.

In 16th century it was again attacked by enemy navies, as for example Drake Pirate's. During the next two centuries it continued receiving attacks. It was then the main harbor of Vigo and, although it was involved into the expulsion of Napoleon's army, it could not do anything against the English-Netherlands army in the sink of Rande's galleons. In 19th century it started the loss of importance of its harbor. [18]

# DEMOGRAPHY AND POPULATION

Looking at 2004 census, there are 11.337 inhabitants in Baiona. 5.597 of them are men (49’36%) and 5.740 are women (50’64%). As this is the last census, we will take these data as current data. [20]

The evolution of population is as follows:

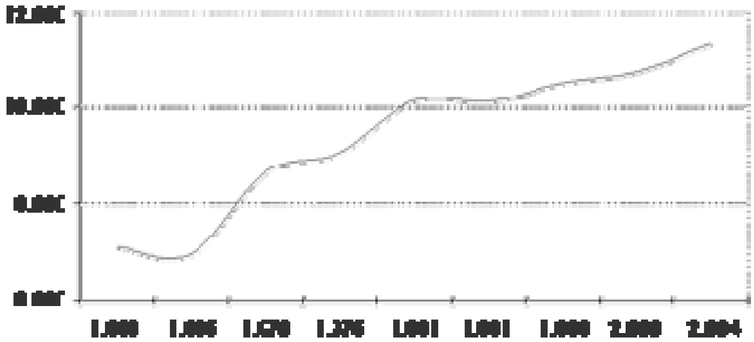

**Figure 12. Population evolution in Baiona**

And the population pyramid is the next one:

| AGE | NUMBER OF PEOPLE | % |
|---|---|---|
| 85 or more | 187 | 1.64 |
| 80 to 84 | 215 | 1.89 |
| 75 to 79 | 299 | 2.63 |
| 70 to 74 | 408 | 3.59 |
| 65 to 69 | 497 | 4.38 |
| 60 to 64 | 551 | 4.86 |
| 55 to 59 | 698 | 6.15 |
| 50 to 54 | 773 | 6.81 |
| 45 to 49 | 791 | 6.97 |
| 40 to 44 | 852 | 7.51 |
| 35 to 39 | 907 | 8.00 |
| 30 to 34 | 948 | 8.36 |
| 25 to 29 | 1033 | 9.55 |
| 20 to 24 | 892 | 7.86 |
| 15 to 19 | 705 | 6.21 |
| 10 to 14 | 574 | 5.06 |
| 5 to 9 | 492 | 4.33 |
| 0 to 4 | 465 | 4.10 |

**Table 2. Population in Baiona**

*Data source: Baiona town council.

The same data in a graphic way:

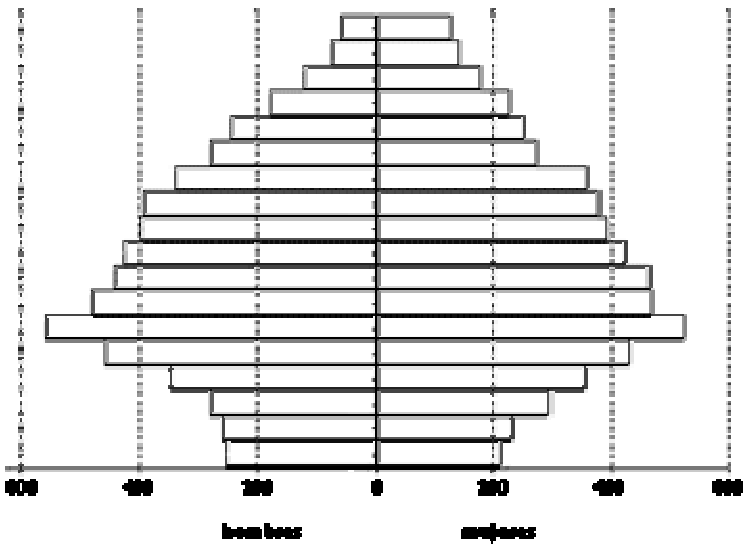


**Figure 13. Population pyramid in Baiona**

Where men are on the left side and women are on the right side. Every step corresponds to the ages mentioned above.

# 4. CHOSEN DEVICES

## Access Point

After taking a look to the possible Access Points we can use, the chosen one has been Alvarion® Wi$^2$ **.** According to the supplier's web page,

*"Wi$^2$ provides an easy-to-deploy outdoor Wi-Fi Mesh access solution integrated with built-in management and OSS support, as well as readiness for immediate connection with the robust QoS capabilities of a BreezeMAX®/BreezeACCESS® backhauling network.*

*Services delivered with Wi$^2$ range from basic public Internet access to public safety, traffic management, video surveillance, indoor coverage and other advanced voice, video and mobile applications."* [21]


**Figure 14. Alvarion® Wi2 Access Point**

This access point offers a great solution for us, fulfilling two goals. The first one and most important is offering a Wi-Fi Access Point for the users. This device is completely compatible with 802.11g standard and will cover all our users' needs. Besides, it provides the perfect combination between price and reliability.

Wi² key applications are:

- Public Internet access
- Voice
- Video surveillance
- Traffic management
- Indoor Wi-Fi coverage
- Outdoor workers
- Public safety
- Homeland security
- Transportation
- Nomadic and mobile applications

From the datasheet we can obtain the next data [22]:

**TX Power and RX Sensitivity**

| 802.11g | 6 Mbps | 9 Mbps | 12 Mbps | 18 Mbps | 24 Mbps | 36 Mbps | 48 Mbps | 54 Mbps |
|---|---|---|---|---|---|---|---|---|
| TX power (dbm) | 20 | 20 | 20 | 20 | 20 | 19 | 19 | 18 |
| RX sensitivity (dbm) | -95 | -93 | -87 | -84 | -80 | -77 | -73 | -70 |

Data rates for 802.11g: 6, 9, 11, 12, 18, 24, 36, 48, 54 Mbps per channel.

Maximum clients: 128 for the radio interface set to access point mode.

Antenna specification: 2x 8dBi omnidirectional (2.4 – 2.5 Ghz).

## Cable

When choosing the cable, it is really important to know that this element can create a big amount of loss in the signal level.

In our system, this is going to be critical, so it is worth spending more money in a good cable with almost no attenuation in order to offer a better service and increase the distance between Access Points.

This table shows the attenuation of the signal depending on the cable at 2.4 Ghz. [23]

| Type of cable | Loss @ 2.4Ghz (dB/m) |
|---|---|
| LMR-100 | 1.3 |
| LMR-195 | 0.62 |
| LMR-200 | 0.542 |
| LMR-240 | 0.415 |
| LMR-300 | 0.34 |
| LMR-400 | 0.217 |
| LMR-500 | 0.18 |
| LMR-600 | 0.142 |
| LMR-900 | 0.096 |
| LMR-1200 | 0.073 |
| LMR-1700 | 0.055 |
| RG-58 | 1.056 |
| RG-8X | 0.758 |
| RG-213/214 | 0.499 |
| 9913 | 0.253 |
| 3/8” LDF | 0.194 |
| 1/2" LDF | 0.128 |
| 7/8” LDF | 0.075 |
| 1 1/4” LDF | 0.056 |
| 1 5/” LDF | 0.046 |

**Figure 15. Attenuation depending on cables**

Taking a look at the table above, we should choose a LMR-900 cable.


**Figure 16. LMR-900 cable**

The cable will be the LMR-900-DB, suitable for outdoor connections. [24]

We will have about 15 m of cable between the DSL socket and the AP, so

$$15 \times 0.096 = 1'44dB$$

which is a completely acceptable attenuation due to the cable.

## CONNECTORS

We will use standard N antenna connectors. These connectors can be exemplified by a 0.5 dB loss.

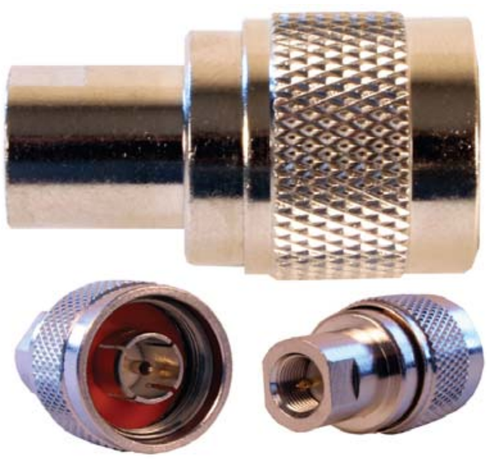

**Figure 17. N connectors**

## ROUTERS

We will need 9 routers to connect the Access Points to the DSL wired network. This way, the routers will be the door between our network and the Internet.

The chosen router is Linksys E3000, with four Ethernet ports.


**Figure 18. Linksys E3000 router**

# 5. IMPLEMENTED SOLUTION

The aim of this project is offering an Internet connection to the citizens of Baiona by a completely wireless network.

To avoid the possible saturation of the links and the devices, the chosen network topology is mesh.

Once we have studied the suitable possibilities, it is time to decide how we are going to implement the chosen solution. As written above in a previous paragraph, the chosen standard is 802.11g (Wi-Fi). This standard has been chosen because of several advantages:

- WiFi products are extensively available in the market. There are different brands of access points and user's network interfaces are able to inter-operate at a very basic service level.
- Prices are considerably lower as competition amongst vendors' increases.
- WiFi networks can support roaming. This allows mobile users with laptop computer to be able to move from one access point to another.
- Numerous access points and network interfaces support various degrees of encryption to protect traffic from interception.
- Reduces the clutter of wires and cables behind your Desktop/ Notebook.
- You can save the cost of cabling and the cost on Network sockets.
- Network Cables and Sockets tend to deteriorate over time, while Wi-Fi does not have this disadvantage.

- Nowadays, most of laptops in the market are provided with a compatible 802.11g Wi-Fi card. Moreover, in case of lack of the card, the prices are affordable.

# CHOSEN PARAMETERS

– Net topology:

We are going to implement a mesh topology. The biggest inconvenient of this kind of topology, as mentioned before, is the great cost. This cost is due to interconnecting every node with cable, what will be avoided with wireless technology. Summing up, this topology will offer us these advantages:

- It is possible to take messages from one node to another for more than one way.
- There is not any interruption in the communications.
- Every server has its own communications with all the other servers.
- If a node fails, another one will take charge of the traffic.
- It does not require a central node or server, so the maintenance gets reduced.
- If a node disappears or fails, it does not affect the other nodes at all.

– Frequency:

802.11g standard works at 2.4 Ghz frequency, which is available almost all over the world.

– Bandwidth:

802.11g standard offers a theoretical maximum speed up to 54 Mbps. However, in practice it reaches about 30 Mbps.

– Antenna:

We will use vertical antennas.

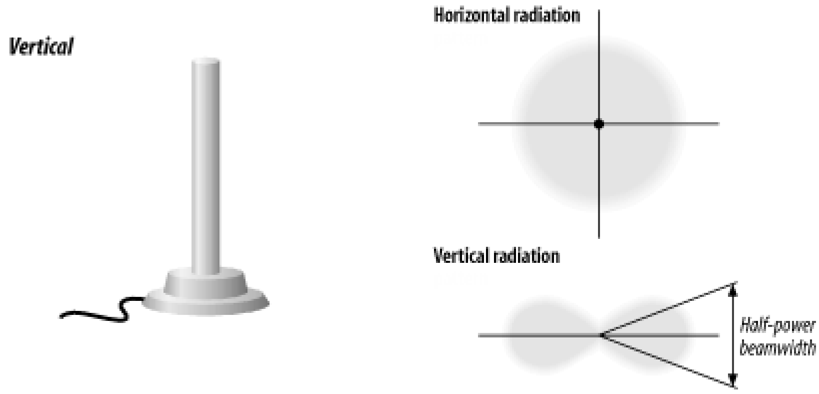


**Figure 19. Vertical antennas**

Vertical are one kind of omnidirectional antennas. Most of suplliers sell several kind of vertical antennas, variating mainly the gain, which can be form 3 dBi to 17 dBi.

A vertical antenna is omnidirectional just on the horizontal level. In 3D, its radiation pattern is like a donut. A higher gain means the donut is squashed. It also means that the antenna is bigger and more expensive, but there are not specially big antennas for 802.11.

# USERS CALCULATION

In the study "Evolución de los usos de Internet en España 2009" (Evolution of Internet usage in Spain 2009) we obtain important data in order to develop the needed research for our network. Relating to Internet access in Spain, 61'7% of people between 10 and 74 years old connect to the Internet. [25]

According to the data obtained from Baiona's town council, we can calculate how many people are there in Baiona between 10 and 74 years old.

$408 + 497 + 551 + 698 + 773 + 791 + 852 + 907 + 948 + 1033 + 892 + 705 + 574 = 9629$ people.

This amount of people is up to 85'31% of total.

Basing on the study previously commented, we can assume that 61’7% of people between 10 and 74 years old in Baiona will access to the Internet.

$$\frac{61'7}{100} \times 9629 = 5941'093 \approx 5942$$

We should notice that not every user has a suitable for connection device. Usually a family share a personal computer or laptop, maximum two. For this reason, we will divide the number of users by a factor equal to 2.5. Tis will give us a closer idea of how many devices will there be connected maximum at the same time.

$$\frac{5941'093}{2'5} = 2376'437 \approx 2377 users$$


**Figure 20. Baiona's surface**

# LINK CALCULATION

In this section the aim will be calculating how many access points do we need for covering the needs.

We will have two main discriminators: the number of users (with the capacity we want to offer to any of them) and the area we have to cover.

Here we will make the calculation of the number of Access Points in both scenarios. The most restrictive situation will be chosen as the good one, so we will be sure we cover both number of users and area surface.

- **NUMBER OF AP DEPENDING ON THE NUMBER OF USERS**

First of all, we have to decide the speed of the access we are going to offer to the citizens in Baiona. 2 Mbps is a very reasonable speed.

Besides, we have to keep in mind that statistically not every user is receiving or sending information continuosly. However, usually a customer enters a link on his browser, downloads the web page, reads it and after few instants clics another link or makes another search. Basing on this, we can share the capacity of the link between 10 people.

$$\frac{2377 users \times 2 Mbps}{10} = 475'4 Mbps$$

As we can see, the total expected capacity of our network is 475’4 Mbps.

Every Access Point can manage up to 54 Mbps. However, to be honest we should decrease that speed. Besides, every AP will have to be capable to manage its users and, in case of having another AP connected as a “bridge”, the second AP’s users. It is also important to know that some of that bandwidth will be used for signalling.

For these reasons, we can assume that every AP can manage up to 20 Mbps.

Dividing the total capacity by the capacity of one single AP, we can find the needed number of APs.

$$\frac{475'4Mbps}{20\frac{Mbps}{AP}} = 23'77APs \approx 24APs$$

- **NUMBER OF AP DEPENDING ON THE AREA TO COVER**

For this calculation, we need to modelate the behavior of the electromagnetic waves. That is the only way we can calculate the maximum distance of the link. [26]

To be precise, we have to calculate the link balance:

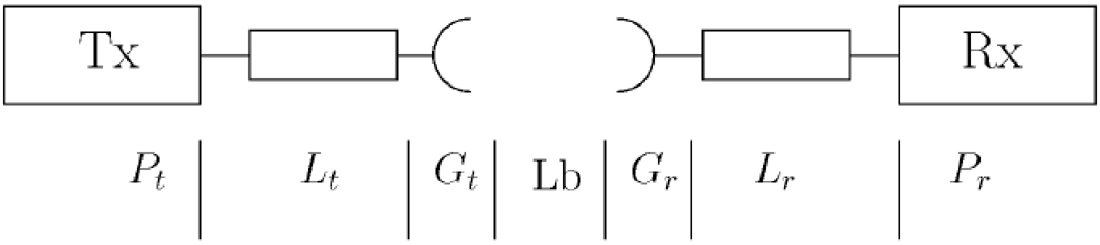


**Figure 21. Link balance**

Where:

- Pt is the transmitted power (dBm)
- Lt are the losses in the transmitter (dB), caused by the cables and connectors.
- Gt is the gain of the transmitter antenna (dBi)
- Lb are the free space loss (dB). Depending on the model we use, these losses are modelled in a different way.
- Gr is the gain of the receptor antenna (dBi).
- Lr are the losses in the receptor (dB), caused by the cables and connectors.
- Pr is the received power or sensitivity of the receiver antenna (dBm).

The equation to solve is the next one:

$$Pt - Lt + Gt - Lb + Gr - Lr = \mathrm{Pr}$$

Let’s take a look at the parameters we have:

Pt can be found in the characteristics sheet of the $Wi^2$ Access Point. Looking at it we can see that, working at 24Mbps, the transmitting power is 20 dBm.

Lt can be calculated easily. We have seen that, for 15 mts of cable, the attenuation is 1’44 dB. Besides, the losses in the connectors are 0’5 dB. Finally: Lt=1’94 dB.

We can get Gt directly from the datasheet. Gt=8dBi.

However, the current regulation does not allow more than 20 dB going out from the transmitting antenna. It is to say: the transmitting power minus the losses in the transmitter plus the antenna gain can never exceed 20 dB. For this reason, we will decrease transmitting power. The transmitting power will be Pt= 20-8+1’94=13’94dBm.

Lb will be our variable, because we want to know the maximum distance of the link. Calculating Lb, which is in function of the distance between antennas, we will be able to calculate the maximum link distance.

Gr can be found in datasheet as well. 8dBi.

Lr is calculated the same way like Lt. Lr=1’94 dB.

Pr can be found in the datasheet. At 24 Mbps speed, the sensitivity is -80 dBm. We have to let a sensitivity margin of 10 dBm in order to make sure that our signal will be received. So Pr= -70dBm.

Once we know all the data we can proceed with the calculation.

$$
\begin{aligned}
&13'94 - 1'94 + 8 - Lb + 8 - 1'94 = -70 \Rightarrow \\
&20 - Lb + 6'06 = -70 \Rightarrow \\
&26'06 - Lb = -70 \Rightarrow \\
&Lb = 96'06dB
\end{aligned}
$$

Now we can calculate the distance that causes those losses. We can not use the free space loss model because it is suitable for big cleared areas without obstacles.

However, we will use Hata model. Hata Model for Urban Areas, also known as the Okumura-Hata model, is the most widely used radio frequency propagation model for predicting the behavior of cellular transmissions in built up areas. This model also has two more varieties for transmission in Suburban Areas and Open Areas.

Hata equation for urban areas is the next one:

$$Lb = A + B \times \log(r)$$
$$A = 69'55 + 26 \times \log(f) - 13'82 \times \log(hb) - a(hm)$$
$$B = 44'9 - 6'55 \times \log(hb)$$

The expression for a(hm) depends on the size of the city. We will use the expression for a small city:

$$a(hm) = (1'1 \times \log(f) - 0'7)hm - (1'56 \times \log(f) - 0'8)$$

Please, notice that f has to be in Mhz, h in meters and r in Km.

$$a(hm) = (1'1 \times \log(2400) - 0'7)10 - (1'56 \times \log(2400) - 0'8) \Rightarrow$$
$$a(hm) = (3'018) \times 10 - 4'4731 \Rightarrow$$
$$a(hm) = 25'71$$

With this data, now we can calculate A and B:

$$A = 69'55 + 26 \times \log(2400) - 13'82 \times \log(10) - 25'71 \Rightarrow$$
$$A = 69'55 + 87'88 - 13'82 - 25'71 \Rightarrow$$
$$A = 117'9$$

$$B = 44'9 - 6'55 \times \log(10) \Rightarrow$$
$$B = 38'35$$

Finally, and knowing the maximum Lb, we can find the maximum link distance:

$$96'06 = 117'9 + 38'35 \times \log(r) \Rightarrow$$
$$\frac{96'06 - 117'9}{38'35} = \log(r) \Rightarrow$$
$$-0'569 = \log(r) \Rightarrow$$
$$r = 0'269km$$

We can conclude that the maximum distance between antennas that will make possible the link is 269 meters.

The area covered by one Access Point is

$$area = \pi \times r^2$$

As we have just calculated, the radio we are going to use is 550m

$$area = \pi \times 0'269^2 \Rightarrow$$
$$area = 0'2273Km^2$$

As written in the section “population of study”, Baiona has a surface of 34’7 Km$^2$.

Dividing the area by the area of coverage of one AP, we can calculate how many AP we need.

$$\frac{34'7}{0'2273} = 152,66 \approx 153 stations$$

However, this is not the real number. 34’7 Km$^2$ is not the urbanized area, it includes forest and beach. It makes no sense offering service to non-urbanized areas, so with the help of Google Earth Pro® and its tool “POLIGON” we will calculate the urbanized surface. [27]

As we saw in a previous map, Baiona is divided in 5 parishes. That surface is what we are going to calculate.

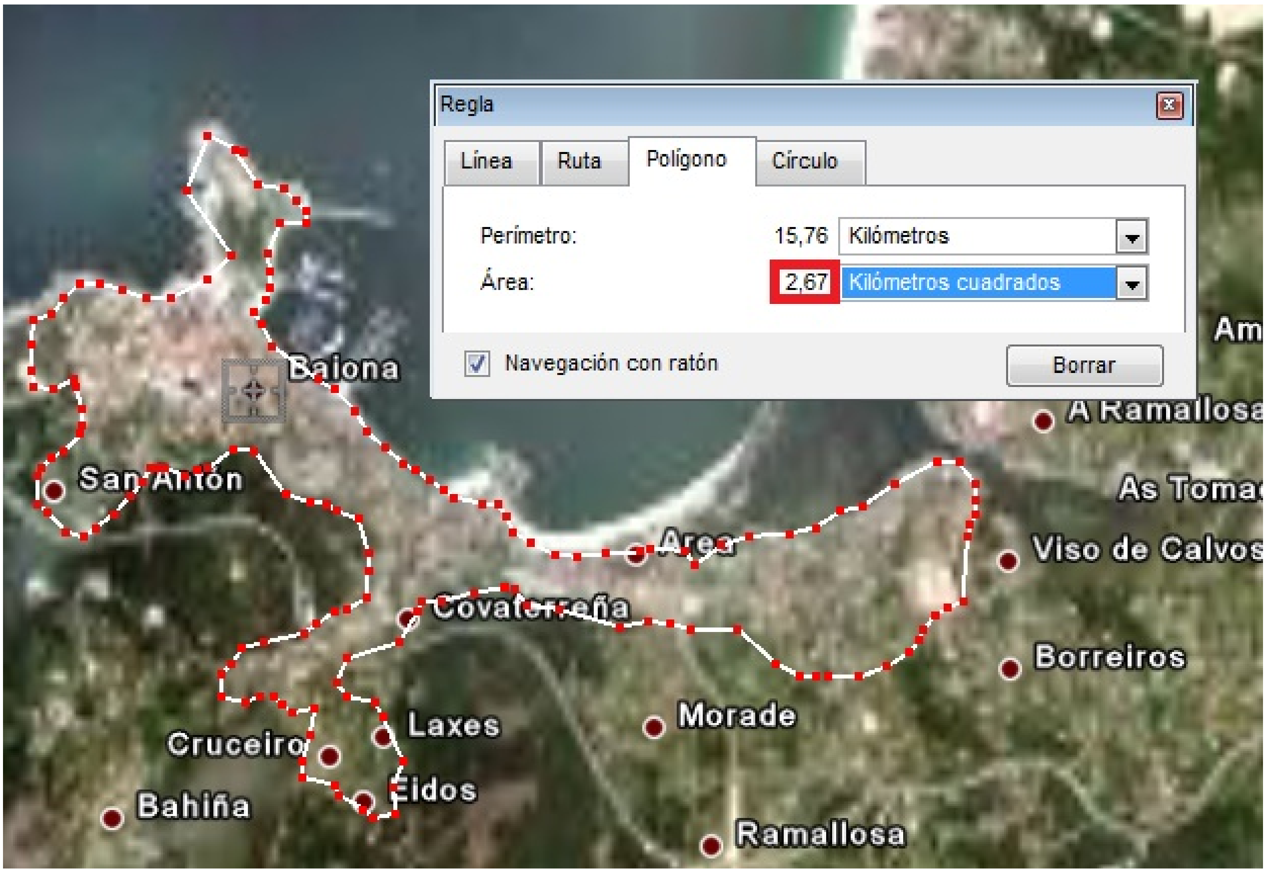


**Figure 22. Surface**


**Figure 23. Surface**


**Figure 24. Surface**

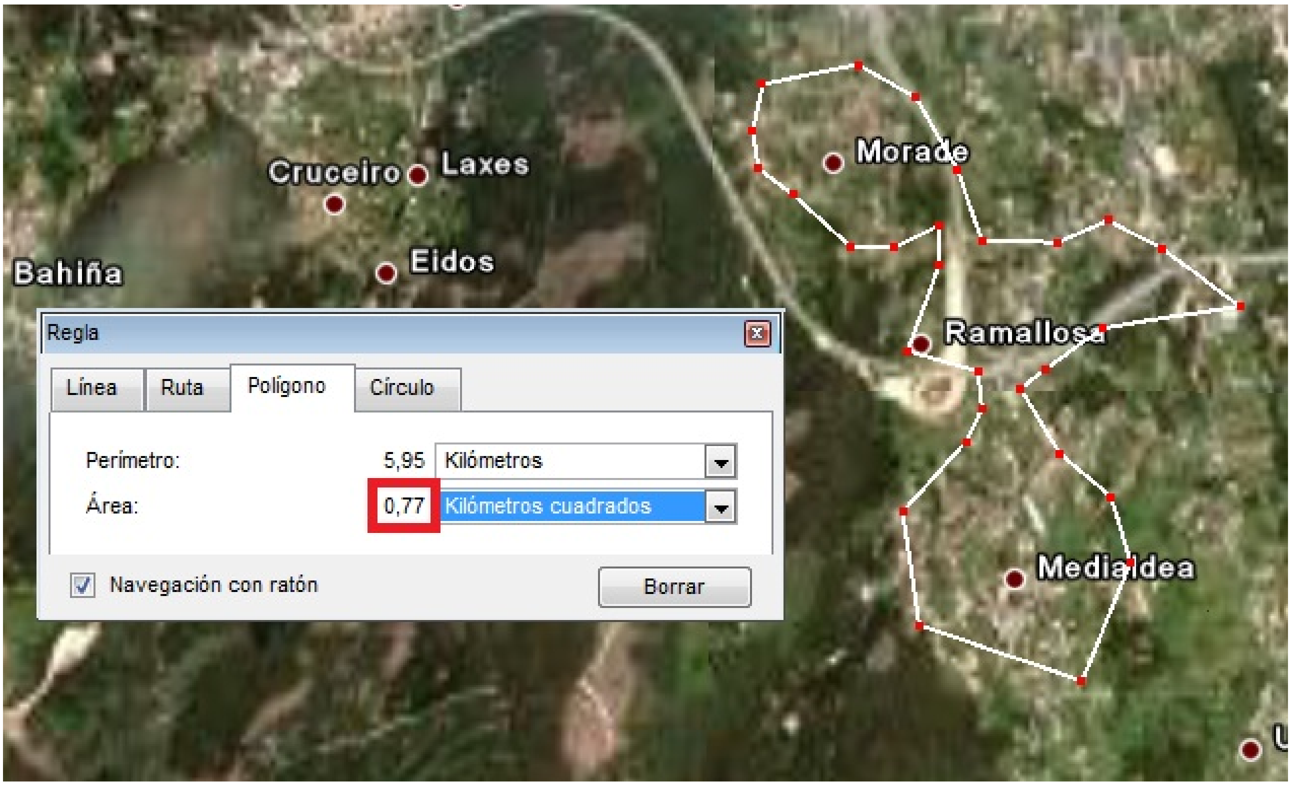


**Figure 25. Surface**

Calculating the whole area:

$$2'67 + 0'42 + 0'50 + 0'77 = 4'36 km^2$$

This means that the urbanized area is much smaller than the municipality area, what will allow us reduce considerably the number of Access Points to use.

$$\frac{4'36}{0'2273} = 19'18 \approx 20AP$$

As we can see, the most restrictive number of Access Points is still 24, imposed by the traffic generated by the users. 24 APs is more than the real needs of area, so we will divide them proportionally depending on the surface of the parishes.

| Parish | Surface (km$^2$) | % Total surface | Number of AP |
|---|---|---|---|
| Baiona | 2’67 | $\frac{2'67}{4'36} \times 100 = 61'23\%$ | $\frac{61'23}{100} \times 24 = 14'69 \approx 15$ |
| Baredo | 0’42 | $\frac{0'42}{4'36} \times 100 = 9'63\%$ | $\frac{9'63}{100} \times 24 = 2'31 \approx 3$ |
| Bahiña | 0’5 | $\frac{0'5}{4'36} \times 100 = 11'47\%$ | $\frac{11'47}{100} \times 24 = 2'75 \approx 3$ |
| Belesar and Sabaris | 0’77 | $\frac{0'77}{4'36} \times 100 = 17'66\%$ | $\frac{17'66}{100} \times 24 = 4'24 \approx 5$ |
| | | **TOTAL** | **26** |

**Table 3. APs in every parish**

The total number of Access Points has increased. This is due to the division we made. It is impossible placing decimal APs, so we had to round up in order to offer the service we wanted to offer.

Basing on the analysis done, the most restrictive number of Access Points is imposed both by the number of users and the area to cover.

<u>We will install 26 Access Points.</u>

# ACCESS POINTS ARRANGEMENT

Due to speed reasons, it is not suitable connecting all the APs in a row, because it would highly decrease the speed offered to the users connected to the last APs of the row. Besides, every Alvarion® Wi$^2$ can get connected up to five Access Points and we will use that characteristic.

The Access Points will be placed forming groups of 3 Access Points, where the central one will be connected by DSL to the main network, and the other 2 will work in bridge mode, extending the main one's signal.

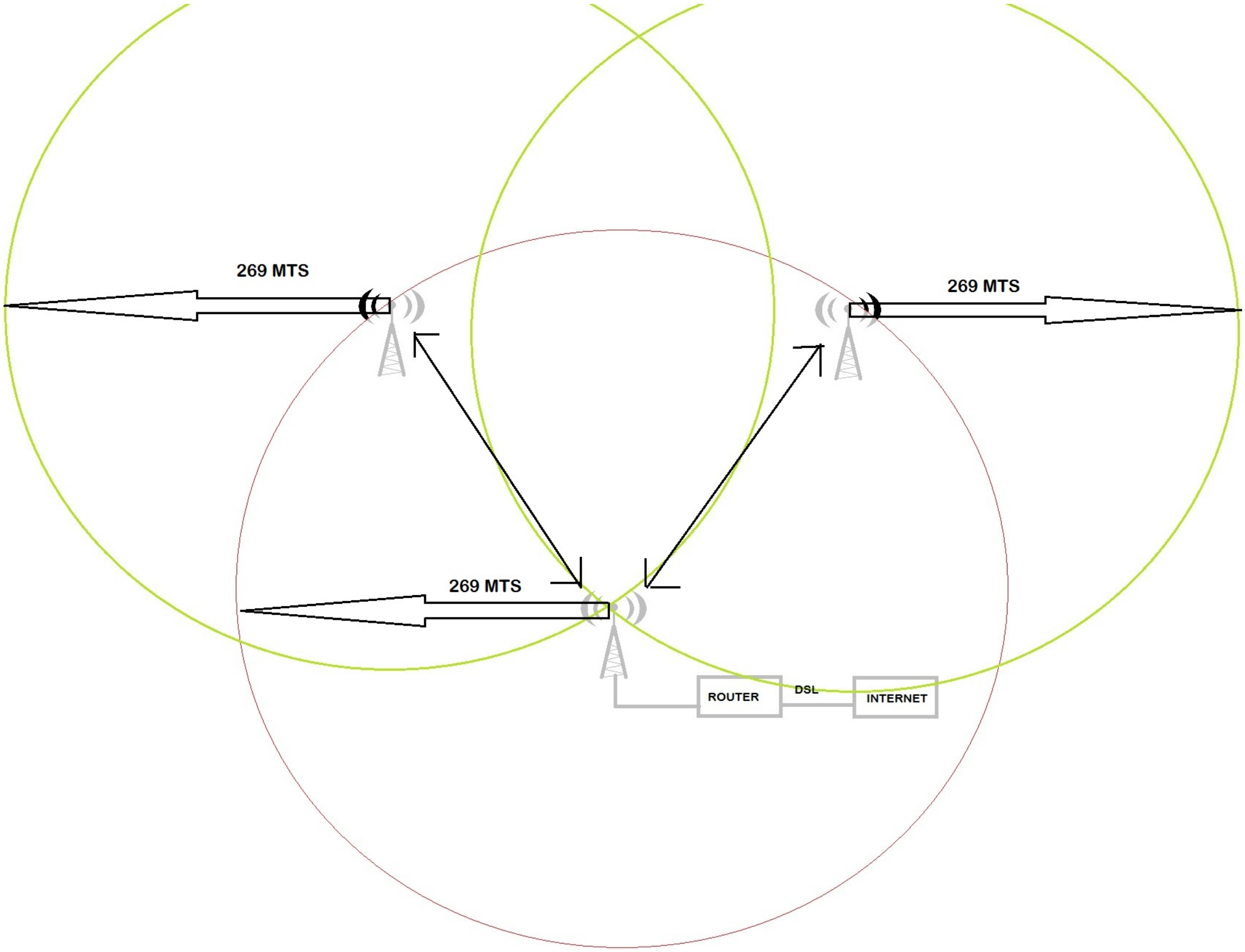


**Figure 26. AP arrangement**

This way we will give coverage to all the users in Baiona.

As we can see in Alvarion® Wi$^2$ datasheet, every AP has two omnidirectional antennas. One of those antennas will be used for linking the APs, and the other one will be in charge of providing service to the users.

This way, the access is completely provided and guaranteed.

# ACCESS POINTS PLACEMENT

In this scheme, we will place the Access Points in the map, so we will see how could they be placed to offer a good service.

With the program Google Earth Pro® we can use the tool “CIRCLE” to make a circle of the selected radio. We selected a radio of 270 meters and placed it along the way.

In the next picture we can see how the Access Points are placed. The red circles correspond to stations connected by DSL to the Internet, and the green ones are configured as bridges of the main ones.

It can be seen that the number of Access Points by parish calculated before is correct and gives coverage to the municipality.

The Antennas will be placed over public buildings, except the one who will be placed over the town council’s rooftop. The town council will have to pay a rent to those buildings in order to place the antennas there.

The chosen APs have two omnidirectional antennas. One of them will be used to connect the stations between them and the other one will be used to offer service to the users in Baiona.

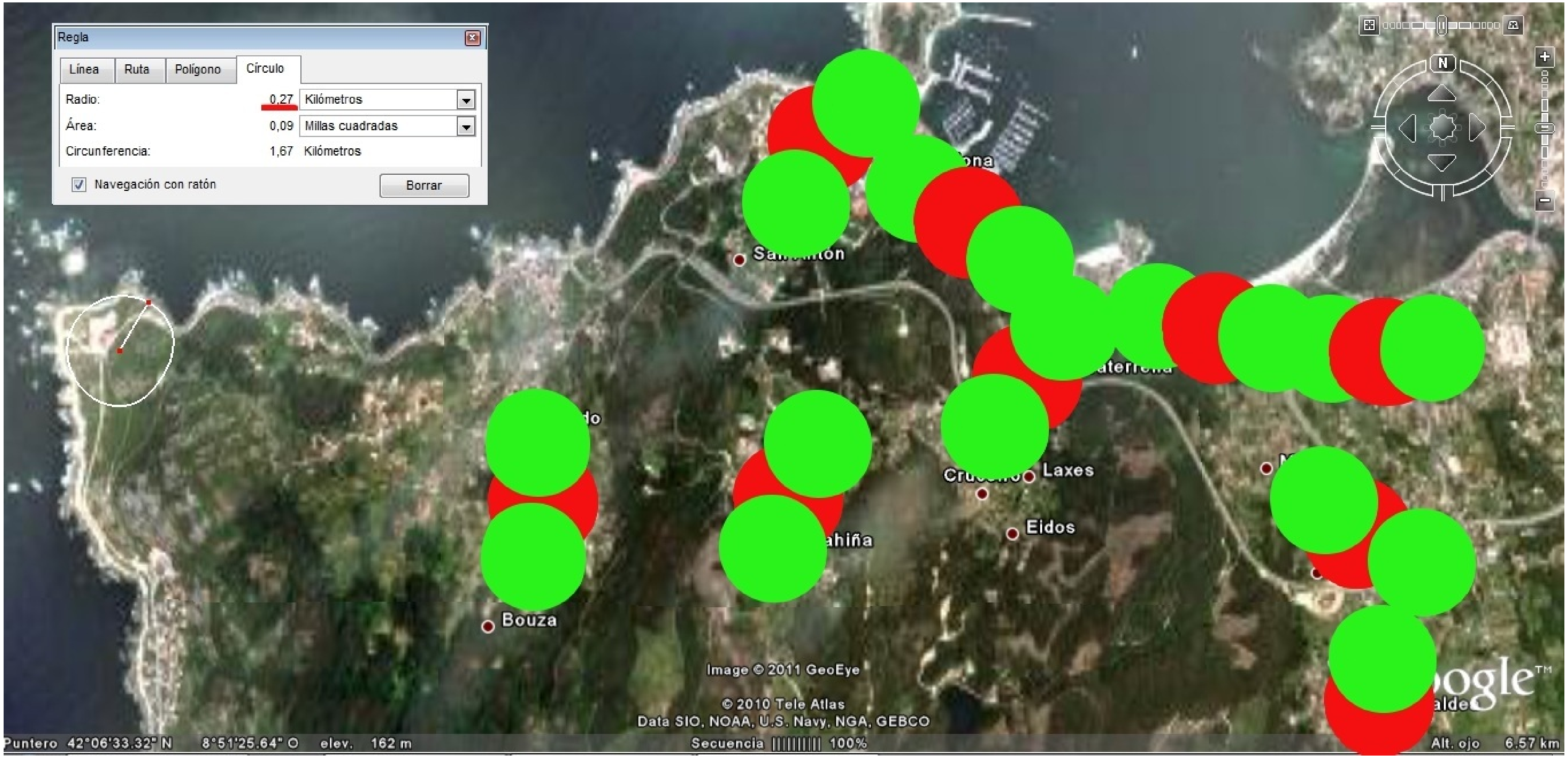


**Figure 27. Access Points placement**

# THROUGHPUT CALCULATION

In this section we will calculate how much traffic has to outstay one Access Point. It is important to analyze the worst possible case. This case will have place in the APs connected to the Internet, because they will have to take their own traffic and, besides, the bridge APs' traffic.

In the section: "Link Calculation depending on the number of users" we said that every AP would be able to manage up to 20Mbps in order to offer 2Mbps to each user. However, we know that BreezeACCESS Wi$^2$ can manage 54 Mbps maximum.

Taking a look at the design of the APs arrangement we can see that one AP has to be able to take the traffic of 3 APs: itself and two bridges.

In this case, 3x20=60Mbps, what exceeds the maximum speed of BreezeACCESS Wi$^2$. In spite of this, this will happen just in extreme cases, when the offered speed for every user will get lightly decreased.

This decrease of speed is completely acceptable because it makes no difference at all and will happen almost never.

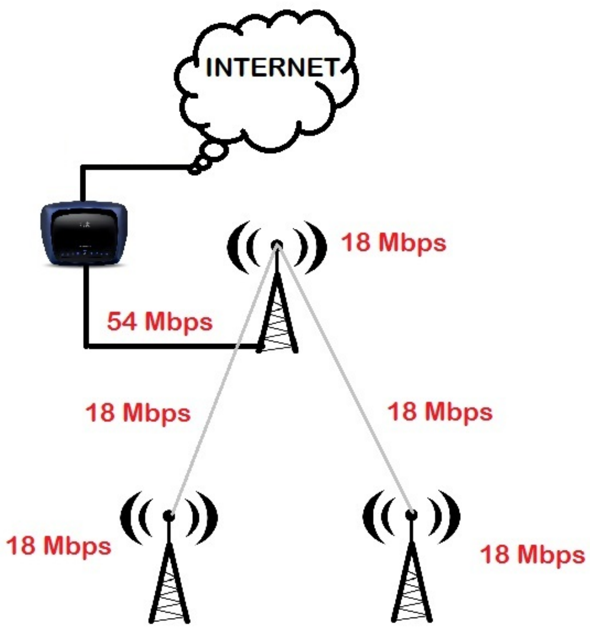


**Figure 28. Throughput calculation**

# 6. ECONOMY

This section does not try to be a detailed economic study of the network. The idea is having a wide view of the cost of the network and the devices we are going to use.

It is important to notice that, depending on the market, the brand, the moment… the prices oscillate significantly. For this reason, all the prices are just orientative.

The aim of this network is providing a public Internet access to all the citizens in Baiona and, as it was commented in the introduction, Internet is now so important that can be treated as a right of the citizens, so Baiona's Town Council will not get paid any money for this access. It will be treated as an increment of the living standard in Baiona.

| Device | Price | Amount | Total Price |
|---|---|---|---|
| Alvarion® Wi$^2$ | 1700€ | 26 | 44.200€ |
| LMR-900 cable | 13.85€/m | 135 | 1.869'75€ |
| Linksys E3000 | 134€ | 9 | 1206€ |

**Table 4.Devices Prices**

The total price of the used devices will be

$$44200 + 1869'75 + 1206 = 47.275'75€$$

Now we will calculate the manpower cost:

| Installation | Man-hours | Man-hour € | Nº of installations | Total |
|---|---|---|---|---|
| Alvarion® BreezeACCESS Wi$^2$ | 6 | 12€ | 26 | $6 \times 12 \times 26 = 1872€$ |
| Cable deployment | 12 | 12 | 1 | $12 \times 12 = 144€$ |

**Table 5. Manpower prices**

The total price of manpower is:

$$1872 + 144 = 2016€$$

We also have to calculate the prices of renting:

| Concept | Amount | €/month | Total/month |
|---|---|---|---|
| Placing antennas on rooftops | 25 | 800 | $25 \times 800 = 20000€$ |
| ISP | 9 | 40 | $9 \times 40 = 360$ |

**Table 6. Renting prices**

Our ISP provider will be Telefonica, the main provider in Baiona and in all Spain.

The total price of rentings is:

$$20000 + 360 = 20.360€ / month$$

With these quantities we can calculate the amortization of the deployment of the network.

We can assume that the network's useful life is 5 years or, what is the same, 60 months. Now we will calculate the amortization of the network per month.

$$\frac{47275'75 + 2016}{60} = 829'0291€$$

$$829'03 + 20360 = 21189'03€$$

We can conclude that the amortized price of the network is <u>21.189'03€ per month.</u>

# 7. ENVIRONMENTAL IMPACT

This chapter defines the basic lines to minimize the environmental impact of a Wi-Fi installation, making reference to the electromagnetic fields and their influence on health.

## AESTHETIC ANALYSIS

The Access Points and the ways of the electric feeding lines have been placed looking for the minimum aesthetic harm possible.

The needed devices will be placed on the roof of buildings, and the electric lines will pass through these buildings' facades, as the current cables.

We have the support of the law. The article 12 of the Directive 2002/21/CE of The European Parliament and the Committee, of March 7th, 2002, about a legal common framework regulator of networks and electronic communications: "the shared use of resources can be profitable by territorial ordination, public health or environmental reasons".

The Royal Decree-Law 1/1998 about common telecommunication infrastructures defines the need of sharing existing networks, promoting the shared placing of them, in order to minimize the visual impact.

Besides, those recent constructed areas, where it has already been applied the Law 38/1999, November 5th, of ordination of edification, where for the first time is established the responsibility of the Municipal Corporation for the buildings to have telecommunications infrastructure, can be profited for this network.

# WI-FI AND ELECTROMAGNETIC FIELDS

The exposition to electromagnetic fields is regulated by the Royal Decree 1006/2001, of 28th of September. In this Decree it is approved the Regulation that establishes protection conditions of the radio electric public domain, restrictions to radio electric emissions and sanitary protection actions against radio electric emissions. [28] [29]

We will calculate the safety distance:

$$Safety\_distance = \sqrt{\frac{M \times PIRE}{4 \times \pi \times S\max}}$$

M is the reflection factor. We will use 4, the worst factor (total reflection).

PIRE will be 100mW, the equivalent to 20dB.

Smax is the maximum power density. For computers emitting between 2 y 300 Ghz, it is $10W/m^2$.

Solving the equation:

$$\sqrt{\frac{4 \times 0'001}{4 \times \pi \times 10}} = \sqrt{\frac{0'004}{125'663}} = 0.0056m$$

We can conclude that there is no risk for the health, because the safety distance is 5’6 cm, and the antennas will never be so close to people.

# 8. CONCLUSIONS

With this thesis, we have demonstrated that the deployment of a wireless area network in an urban area is completely possible. However, it is remarkable that, as the size of the city increases, the complications of installation and deployment increase as well.

Our network is based on new wireless technologies completely implemented nowadays, what makes the access to the Internet suitable for everyone.

Internet is not just fun and leisure time, it is also communication, information and offers a lot of solutions for any kind of job. For these reasons, it should be an undeniable right of every citizen in the so-called “developed countries”.

With this network we succeeded in the aim of finding a good balance between service offered and cost of the network. We hope all the users will be satisfied with the speed offered. Every single effort in this thesis has been made thinking on them, who are going to take profit of this initiative.

Thanks to the current technologies, it was suitable deploying such a big network. Few years ago it would have not been profitable because of the huge expenditure it would have been necessary to make.

About the cost, we have a final amortized economic cost of 21.189’03€ per month. This amount of money is high, but it is because we are offering a really good service to a big amount of people. Besides, it could be affordable for Baiona’s municipality.

Finally, the environmental and health risks have been avoided as much as possible, demonstrating that there is not any risk for people’s health derived from our network.

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# APPENDIX I: SUMMARY IN SPANISH

# APÉNDICE I: (RESUMEN EN ESPAÑOL)

# 1. INTRODUCCIÓN

El propósito de este proyecto es el estudio y desarrollo de una red Wi-Fi en un área urbana con el fin de ofrecer servicio a los habitantes de esa zona.

El propósito es hacer una instalación completa de una Red de Área Local (LAN) completa. Para ello, estudiaremos las opciones disponibles y decidiremos cuál es mejor para el área el que intentaremos dar cobertura. La decisión se basará en la cobertura, la sencillez, la implementación, la comodidad para los usuarios y, por supuesto, la preservación del entorno y el coste del proyecto.

Una vez hayamos decicido qué hacer, será importante cómo hacerlo. Decidiremos qué equipamiento vamos a usar y cuántas estaciones, teniendo en cuenta que demasiadas incrementarán el precio del proyecto y muy pocas harán que empeore la calidad del servicio.

Ofreceremos cobertura a usuarios individuales, no a grandes empresas o empresas gubernamentales como hospitales o estaciones de policía. Esto es por dos razones. La principal es que ese perfil de usuarios necesita una protección de la red muy alta, y una LAN pública nunca es tan segura como una privada. La segunda razón es la enorme cantidad de usuarios por m2 que eso supone. Haremos un estudio de la densidad de población a fin de ofrecer un buen servicio en toda la zona.

Hemos elegido un término municipal que se considera un área urbana en términos de cantidad de habitantes, orografía y ocupación de los habitantes.

A lo largo de este trabajo, me gustaría crear la conciencia de que instalar una red Wi-Fi gratuita para uso público no es caro o difícil en absoluto y supondría un gran paso hacia las tecnologías y necesidades del S.XXI.

En el mundo de hoy en día, la invención de Internet solo se puede equiparar a la invención de la rueda. Ambos cambiaron la forma de comunicarse y comerciar. Ambos significaron un cambio drástico en el modo de vida.

# 2. ESTÁNDAR WIFI

## 802.11

802.11 es un estándar creado por el Instituto de Ingenieros Eléctricos y Electrónicos (IEEE). Este protocolo define los dos niveles OSI de arquitectura más bajos (capas física y enlace de datos), especificando su funcionamiento en una WLAN.

Además de las características de una red cableada, las redes inalámbricas ofrecen principalmente cuatro ventajas:

- Movilidad
- Sencillez de uso e instalación
- Flexibilidad de la instalación
- Reducción de costs.

El mecanismo de acceso especificado por el estándar es CSMA/CA, y la modulación puede ser DSS (Direct Sequence Spread Spectrum) o FHSS (Frequency Hopping Spread Spectrum).

Las velocidad soportada es de 1 a 2 Mbps, y funciona en la banda de frecuencia de 2,4 Ghz (2,412 Ghz – 2,484 Ghz). Esta banda presenta muchas interferencias porque es una banda de acceso público y es usada por teléfonos inalámbricos y hornos microondas, así como muchos otros dispositivos.

Se han implementado mejoras, creando nuevos subestándares.

## 802.11b

802.11b tiene una tasa máxima de datos de 11Mb por segundo, aunque en la práctica el máximo throughput (rendimiento) que una aplicación puede conseguir son 5.9 Mbps usando protocolo TCP y 7.1Mbps usando UDP

Los dispositivos 802.11b sufren interferencias con otros productos que operan en la banda 2.4Ghz.

## 802.11g

802.11g surge como una mejora del estándar 802.11b en 2003. La banda de operación es 2.4 Ghz, pero gracias a la modulación OFDM puede ofrecer hasta 54Mbps de velocidad.

Wi-Fi (Wireless Fidelity) es la empresa que certifica que los dispositivos catalogados como 802.11g cumplen las características especifficadas y pueden funcionar correctamente.

En la siguiente tabla se muestran los canales de 802.11g y sus frecuencias.

| IDENTIFICADOR DE CANAL | FRECUENCIAS PPALES (MHZ) |
|---|---|
| 1 | 2412 |
| 2 | 2417 |
| 3 | 2422 |
| 4 | 2427 |
| 5 | 2432 |
| 6 | 2437 |
| 7 | 2442 |
| 8 | 2447 |
| 9 | 2452 |
| 10 | 2457 |
| 11 | 2462 |
| 12 | 2467 |
| 13 | 2472 |
| 14 | 2484 |

El ancho de banda de la señal, que es 22Mhz, es mayor que el espacio entre dos canals consecutivos (5 Mhz). Es necesario dejar un espacio mínimo de 5 canales para evitar interferencias entre celdas adyacentes.

En este proyecto se ha elegido y se implementará el estándar 802.11g

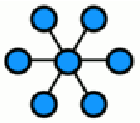
# TOPOLOGÍAS DE RED

La topología de red representa la disposición de los enlaces que conectan los nodos de una red. La distancia entre los nodos, la tasa de transmisión o las interconexiones físicas no pertenecen a la topología, aunque pueden verse afectados por ella.

Discutiremos solo las topologías factibles para una red inalámbrica.

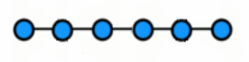
**Topología en estrella**

Cada nodo se conecta a un concentrador central. La ventaja principal es que el fallo de un nodo periférico no afecta al comportamiento del resto de la red. Sin embargo, si falla el nodo central, toda la red podría fallar.



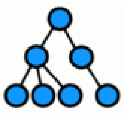
**Topología en línea.**

Nodos conectados uno a uno, formando un enlace punto a punto.



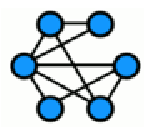
**Topología en árbol.**

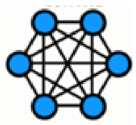
Una colección de redes en estrella dispuestas en jerarquía.



**Topología en red**

Cada nodo está conectado a dos o más nodos.





# MODOS DE OPERACIÓN

El modo de operación de una red define cómo se comunican dos estaciones.

El estándar 802.11 define dos modos de operación: ad-hoc e infraestructura.

**Modo Ad-hoc**

Permite a los clientes de una red inalámbrica comunicarse entre ellos directamente, sin necesidad de un punto de acceso central.

La eficiencia es más baja según aumenta el número de nodos.

**Modo Infraestructura**

Una red en modo infraestructura tiene un elemento central al que deben estar conectados todos los clientes de la red.

Para interconectar muchos puntos de acceso y clientes inalámbricos, todos ellos deben estar configurados con el mismo SSID.

Además de los modos de operación ya vistos, es importante decidir el modo de transmisión. El modo semi-dúplex se define como comunicación bidireccional, pero el envío de información no es simultáneo. Sin embargo, en full-dúplex la información es mucho más eficiente.

# ANTENAS

Una antena es un dispositivo capaz de transmitir y recibir ondas de radio. También se define como el elemento de adaptación entre ondas guiadas, transmitidas por conductores o guías, y ondas que se propagan en espacio abierto.

**Parámetros de las antenas**

Para caracterizar una antena se deben dar los siguientes parámetros:

- **Diagrama de radiación**

Es la representación gráfica de las características de radiación de la antena en función de la dirección angular.

- **Directividad**

La directividad de la antena se define como la densidad de potencia que una antena real radia en la dirección máxima emisión en relación a la densidad de potencia radiada por la antena ideal isotrópica radiando la misma cantidad de potencia.

$$D = \max\left(\frac{\text{Radiated power density }(\theta,\phi)}{\text{Total radiated power}/\,(4\pi)}\right)$$

- **Ganancia**

La ganancia de la antena relaciona la intensidad de una antena en una dirección dada con la intensidad producida por una hipotética antena ideal que radie por igual en todas direcciones (isotrópica) y no tenga pérdidas.

$$Gain = 4\pi\left(\frac{\text{Radiation Intensity}}{\text{Antenna Input Power}}\right)$$

- **Polarización**

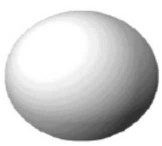
El la polarización electromagnética se define como la figura geométrica que representa el extremo del vector campo eléctrico a una cierta distancia de la antena según el tiempo varía. Este parámetro puede ser lineal, circular o elíptico.

**Tipos de antena**

Existen diferentes tipos de antenas clasificados por su diagrama de radiación.

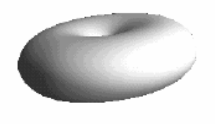
- **Antena isotrópica**

Radia uniformemente en todas direcciones.



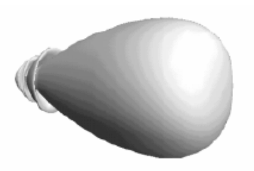
- **Antena omnidireccional**

Radia potencia uniformemente en un plano con una forma de patrón directivo en un plano perpendicular.



- **Antena direccional**

Radia mayor potencia en una o más direcciones, permitiendo reducir las interferencias de fuentes no deseadas. Se usa principalmente en enlaces punto-a-punto.



# 3. SITUACIÓN ACTUAL DE BAIONA

Este capítulo es una pequeña introducción a la población de estudio.

## SITUACIÓN GEOGRÁFICA

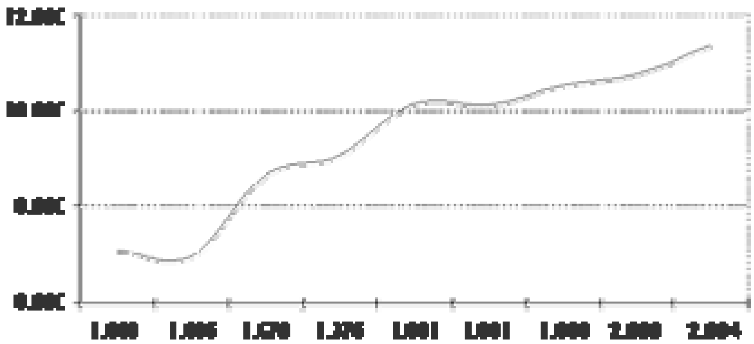
Baiona es uno de los municipios históricos de Pontevedra, una de las cuatro provincias de Galicia, en el noroeste de España. Los habitantes se agrupan en cinco municipios.

- **Altitud mínima:** 0 m (nivel del mar).
- **Altitud máxima:** 632 m (Alto de A Groba).
- **Superficie:** 34,7 km2.
- **Población:** 11.337 habitantes (censo de 2004)

# DEMOGRAFÍA Y POBLACIÓN

De acuerdo al censo de 2004 hay 11.337 habitantes en Baiona. 5.597 son hombres (49’36%) y 5.740 mujeres (50’64%).

La evolución de la población es la siguiente



Y esta es la pirámide de población

| Edad | Número de personas | % |
|---|---|---|
| 85 o más | 187 | 1.64 |
| 80 a 84 | 215 | 1.89 |
| 75 a 79 | 299 | 2.63 |
| 70 a 74 | 408 | 3.59 |
| 65 a 69 | 497 | 4.38 |
| 60 a 64 | 551 | 4.86 |
| 55 a 59 | 698 | 6.15 |
| 50 a 54 | 773 | 6.81 |
| 45 a 49 | 791 | 6.97 |
| 40 a 44 | 852 | 7.51 |
| 35 a 39 | 907 | 8.00 |
| 30 a 34 | 948 | 8.36 |
| 25 a 29 | 1033 | 9.55 |
| 20 a 24 | 892 | 7.86 |
| 15 a 19 | 705 | 6.21 |
| 10 a 14 | 574 | 5.06 |
| 5 a 9 | 492 | 4.33 |
| 0 a 4 | 465 | 4.10 |

# 4.DISPOSITIVO ELEGIDO

## Punto de acceso

El elegido ha sido el Alvarion® Wi$^2$.

Este Access Point ofrece una gran solución para nosotros, cumplimentando dos metas. La primera y más importante es ser un punto de acceso Wi-Fi para los usuarios. Este dispositivo es totalmente compatible con el Standard 802.11g. La segunda es que proporciona la combinación perfecta entre precio y fiabilidad.

De la hoja de especificaciones obtenemos los siguientes datos.

**TX Power and RX Sensitivity**

| 802.11g | 6 Mbps | 9 Mbps | 12 Mbps | 18 Mbps | 24 Mbps | 36 Mbps | 48 Mbps | 54 Mbps |
|---|---|---|---|---|---|---|---|---|
| TX power (dbm) | 20 | 20 | 20 | 20 | 20 | 19 | 19 | 18 |
| RX sensitivity (dbm) | -95 | -93 | -87 | -84 | -80 | -77 | -73 | -70 |

Tasas de datos para 802.11g: 6, 9, 11, 12, 18, 24, 36, 48, 54 Mbps por canal.

Máximo número de clientes: 128

Especificaciones de la Antena: 2x 8dBi omnidireccional (2.4 – 2.5 Ghz).

## Cable

En nuestro sistema va a ser crítica la atenuación introducida por el cable, así que merece la pena invertir más dinero en un cable eficiente.

Tras el estudio de las opciones, el cable elegido es el LMR-900, apto para conexiones al aire libre.


Tenemos 15m de cable entre el socket DSL y el Punto de Acceso:

$$15 \times 0.096 = 1'44dB$$

Lo cual es admisible para el sistema que vamos a implementar.

## CONECTORES

Usaremos conectores N estándar. Para estos conectores se asocian unas pérdidas de 0.5 dB.

## ROUTERS

Necesitaremos routers para conectar los Puntos de Acceso a la red DSL cableada. De esta forma, los routers serán la puerta entre nuestra red a Internet.

El router elegido es el Linksys E3000, con cuatro puertos Ethernet.

# 5. SOLUCIÓN IMPLEMENTADA

El propósito del proyecto es ofrecer una conexión a Internet a los ciudadanos de Baiona mediante una red totalmente inalámbrica.

Para evitar una possible saturación de los enlaces y los dispositivos, la topología de red que utilizaremos será en red.

Como dijimos antes, el estándar elegido es 802.11g (Wi-Fi). Este estándar ha sido elegido por ofrecer numerosas ventajas.

- Los productos WiFi están muy extendidos en el mercado.
- Los precios son considrablemente bajos.
- Las redes WiFi soportan roaming (moverse de un AP a otro sin desconexión).
- Se ofrecen diferentes niveles de encriptación.
- Reduce costs de cableado
- La mayoría de los portátiles son compatibles con este estándar y, en caso contrario, una tarjeta para adaptarlos es económica.

## PARÁMETROS ELEGIDOS

- Topología de Red:

  Vamos a implementar una topología en red.

  - Es posible llevar los mensajes de un nodo a otro por más de un camino.
  - Si un nodo falla, otro se hará cargo del tráfico.

- Frecuencia:

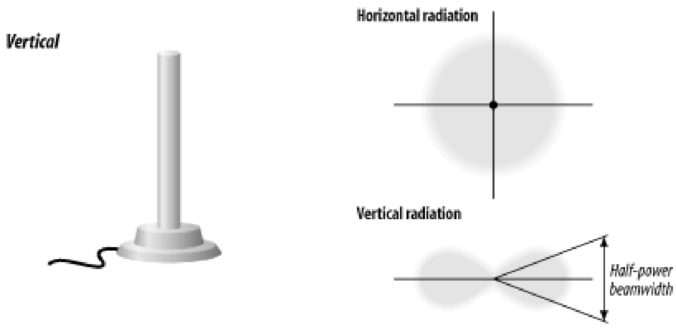
  El estándar 802.11g funciona a 2.4Ghz de frecuencia.

- Ancho de banda:

  Aunque 802.11g ofrece un ancho de banda teórico de 54 Mbps, en la práctica alcanza alrededor de los 30 Mbps.

- Antenas:

  Usaremos antenas verticales.




Una antena vertical es omnidireccional en el plano horizontal. En 3D, su diagrama de radiación es como una rosquilla.

## CÁLCULO DE USUARIOS

En el estudio “Evolución de los usos de Internet en España 2009” obtenemos datos importantes. En relación al acceso a Internet en España, el 61’7% de la gente entre 10 y 75 años accede a Internet.

De acuerdo a los datos obtenidos del concejo de Baiona, podemos calcular cuánta gente está comprendida entre esas edades.

$408+497+551+698+773+791+852+907+948+1033+892+705+574=9629$ personas.

Lo cual representa un 85’31% del total.

Basándonos en el estudio anterior, el 61’7% de esa gente accederá a Internet.

$$\frac{61'7}{100} \times 9629 = 5941'093 \approx 5942$$

Hay que tener en cuenta que normalemtne una familia comparte un PC o portátil, máximo dos. Por esta razón dividiremos los usuarios por un factor 2’5 para tener una idea más cercana del número de usuarios conectados como máximo al mismo tiempo.

$$\frac{5941'093}{2'5} = 2376'437 \approx 2377 users$$

## CÁLCULO DEL ENLACE

Tenemos dos discriminantes: el número de usuarios y el área a cubrir.

- **NÚMERO DE AP EN FUNCIÓN DEL NÚMERO DE USUARIOS**

  Ofreceremos una velocidad de 2 Mbps. Además, ya que un usuario no envía y recibe información constantemente, compartiremos la capacidad del enlace entre 10 usuarios.

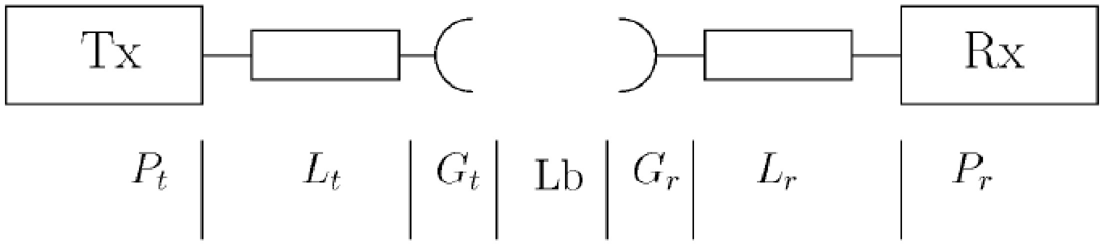
$$\frac{2377 users \times 2 Mbps}{10} = 475'4 Mbps$$

  Debido a que cada AP debe soportar sus usuarios y, en caso de estar conectado como “bridge”, también los usuarios del segundo AP más la señalización en cualquier caso, asumimos que cada AP puede gestionar sólo 20 Mbps.

$$\frac{475'4 Mbps}{20 \frac{Mbps}{AP}} = 23'77 APs \approx 24 APs$$

- **NÚMERO DE AP EN FUNCIÓN DEL ÁREA A CUBRIR**

  Para ser exactos, calcularemos el balance de enlace:




- Pt es la potencia transmitida (dBm)
- Lt son las pérdidas en el transmisor (dB)
- Gt es la ganancia de la antena transmisora (dBi)
- Lb son las pérdidas en espacio libre (dB).
- Gr es la ganancia de la antena receptora (dBi).
- Lr son las pérdidas en el receptor (dB).
- Pr es la sensibilidad de la antena receptora (dBm).

La ecuación a resolver es:

$$Pt - Lt + Gt - Lb + Gr - Lr = \mathrm{Pr}$$

Pt se encuentra en la hoja de características del AP Wi$^2$. A 24Mbps, Pt son 20 dBm.

Para 15 m de cable, la atenuación es 1'44 dB. Además, las pérdidas en los conectores son 0'5 dB. Finalmente: Lt=1'94 dB.

Gt directamente de la hoja de características. Gt=8dBi.

Por legislación no pueden salir más de 20 dB de la antena transmisora. Por esta razón reduciremos la potencia de transmisión. Pt= 20-8+1'94=13'94dBm.

Lb será la variable.

Gr. 8dBi.

Se calcula como Lt. Lr=1'94 dB.

Pr se encuentra en la hoja de características. A una velocidad de 24 Mbps, la sensibilidad es -80 dBm. Dejaremos un margen de 10 dBm para asegurarnos que la señal se reciba, así que Pr= -70dBm.

$$13'94 - 1'94 + 8 - Lb + 8 - 1'94 = -70 \Rightarrow$$
$$20 - Lb + 6'06 = -70 \Rightarrow$$
$$26'06 - Lb = -70 \Rightarrow$$
$$Lb = 96'06dB$$

Calculamos la distancia con el modelo Hata para áreas urbanas.

$$Lb = A + B \times \log(r)$$
$$A = 69'55 + 26 \times \log(f) - 13'82 \times \log(hb) - a(hm)$$
$$B = 44'9 - 6'55 \times \log(hb)$$

La expresión a(hm) depende del tamaño de la ciudad. Usamos la expresión para ciudades pequeñas.

$$a(hm) = (1'1 \times \log(f) - 0'7)hm - (1'56 \times \log(f) - 0'8)$$

F debe estar en Mhz, h en metros y r en Km.

$$a(hm) = (1'1 \times \log(2400) - 0'7)10 - (1'56 \times \log(2400) - 0'8) \Rightarrow$$
$$a(hm) = (3'018) \times 10 - 4'4731 \Rightarrow$$
$$a(hm) = 25'71$$

Ahora podemos calcular A y B:

$$A = 69'55 + 26 \times \log(2400) - 13'82 \times \log(10) - 25'71 \Rightarrow$$
$$A = 69'55 + 87'88 - 13'82 - 25'71 \Rightarrow$$
$$A = 117'9$$

$$B = 44'9 - 6'55 \times \log(10) \Rightarrow$$
$$B = 38'35$$

Ya que conocemos el máximo Lb, podemos calcular la distancia máxima de enlace:

$$96'06 = 117'9 + 38'35 \times \log(r) \Rightarrow$$
$$\frac{96'06 - 117'9}{38'35} = \log(r) \Rightarrow$$
$$-0'569 = \log(r) \Rightarrow$$
$$r = 0'269km$$

La distancia máxima entre antenas es 269 metros.

El area que cubre un AP es:

$$area = \pi \times r^2$$

$$area = \pi \times 0'269^2 \Rightarrow$$
$$area = 0'2273Km^2$$

Como hemos analizado anteriormente, Baiona tiene una superficie de 34’7 $Km^2$.

$$\frac{34'7}{0'2273} = 152,66 \approx 153 stations$$

Sin embargo, quitando áreas no urbanizadas a las que no tiene sentido dar acceso, el número es diferente. Calcularemos el área urbanizada con ayuda de Google Earth Pro® y la herramienta “Polígono”

Calculando el area completa:

$$2'67 + 0'42 + 0'50 + 0'77 = 4'36km^2$$

$$\frac{4'36}{0'2273} = 19'18 \approx 20AP$$

El número de AP más restrictivo es 24, así que esos son los que necesitamos. Ya que tenemos más AP que los determinados por superficia, vamos a repartirlos proporcionalmente en las cinco comarcas.

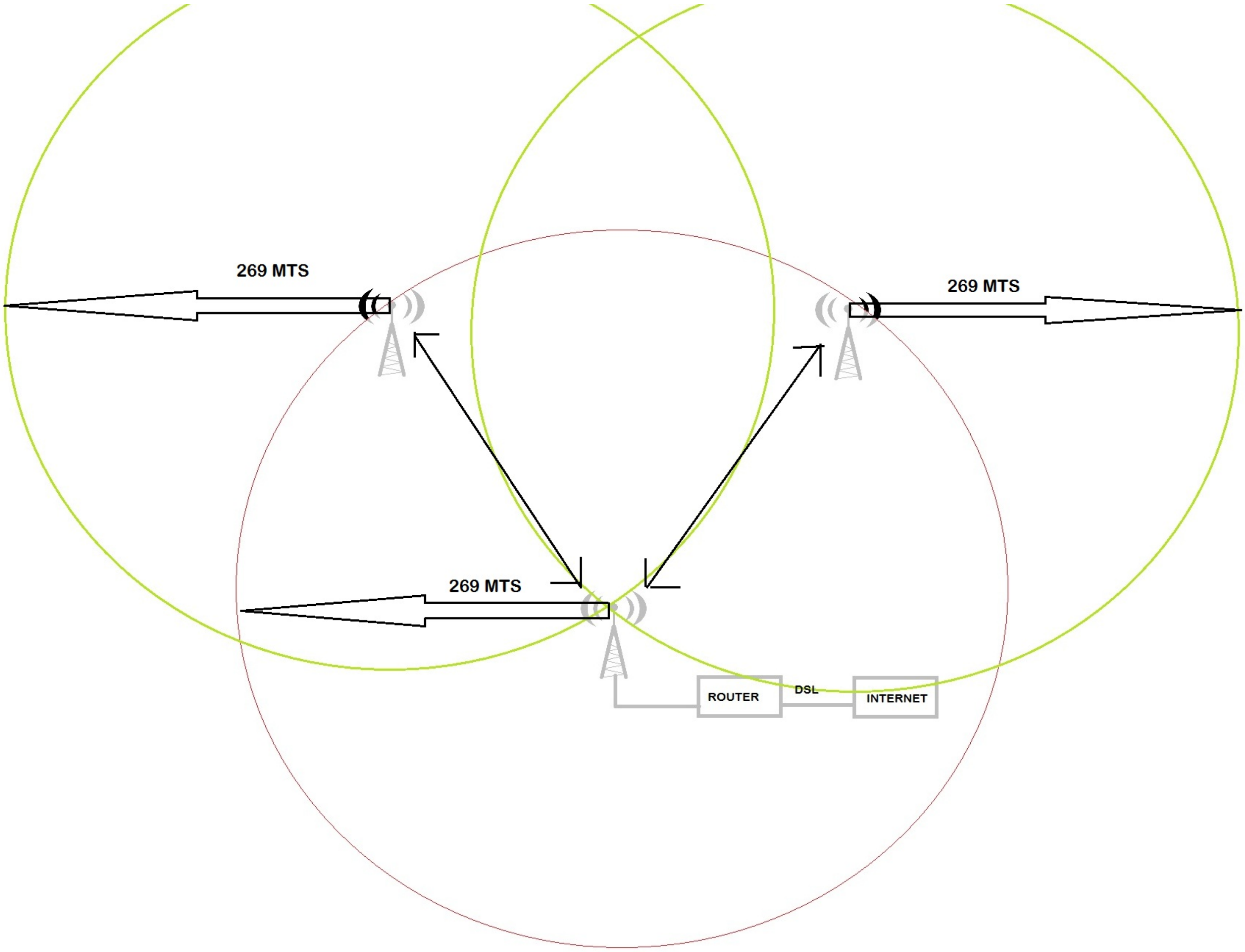
| **Comarca** | **Sup. (km$^2$)** | **% De la sup. total** | **Número de AP** |
|---|---|---|---|
| Baiona | 2'67 | $\frac{2'67}{4'36} \times 100 = 61'23\%$ | $\frac{61'23}{100} \times 24 = 14'69 \approx 15$ |
| Baredo | 0'42 | $\frac{0'42}{4'36} \times 100 = 9'63\%$ | $\frac{9'63}{100} \times 24 = 2'31 \approx 3$ |
| Bahiña | 0'5 | $\frac{0'5}{4'36} \times 100 = 11'47\%$ | $\frac{11'47}{100} \times 24 = 2'75 \approx 3$ |
| Belesar and Sabaris | 0'77 | $\frac{0'77}{4'36} \times 100 = 17'66\%$ | $\frac{17'66}{100} \times 24 = 4'24 \approx 5$ |
| | | **TOTAL** | **26** |

El número total de AP ha aumentado. Esto es por la división que hemos hecho.

Instalaremos 26 Access Points.

# DISPOSICIÓN DE LOS ACCESS POINTS

Se dispondrán en grupos de 3, donde el central estará conectado por DSL a la red principal y los otros 2 trabajarán en modo “Bridge”, extendiendo el alcance.

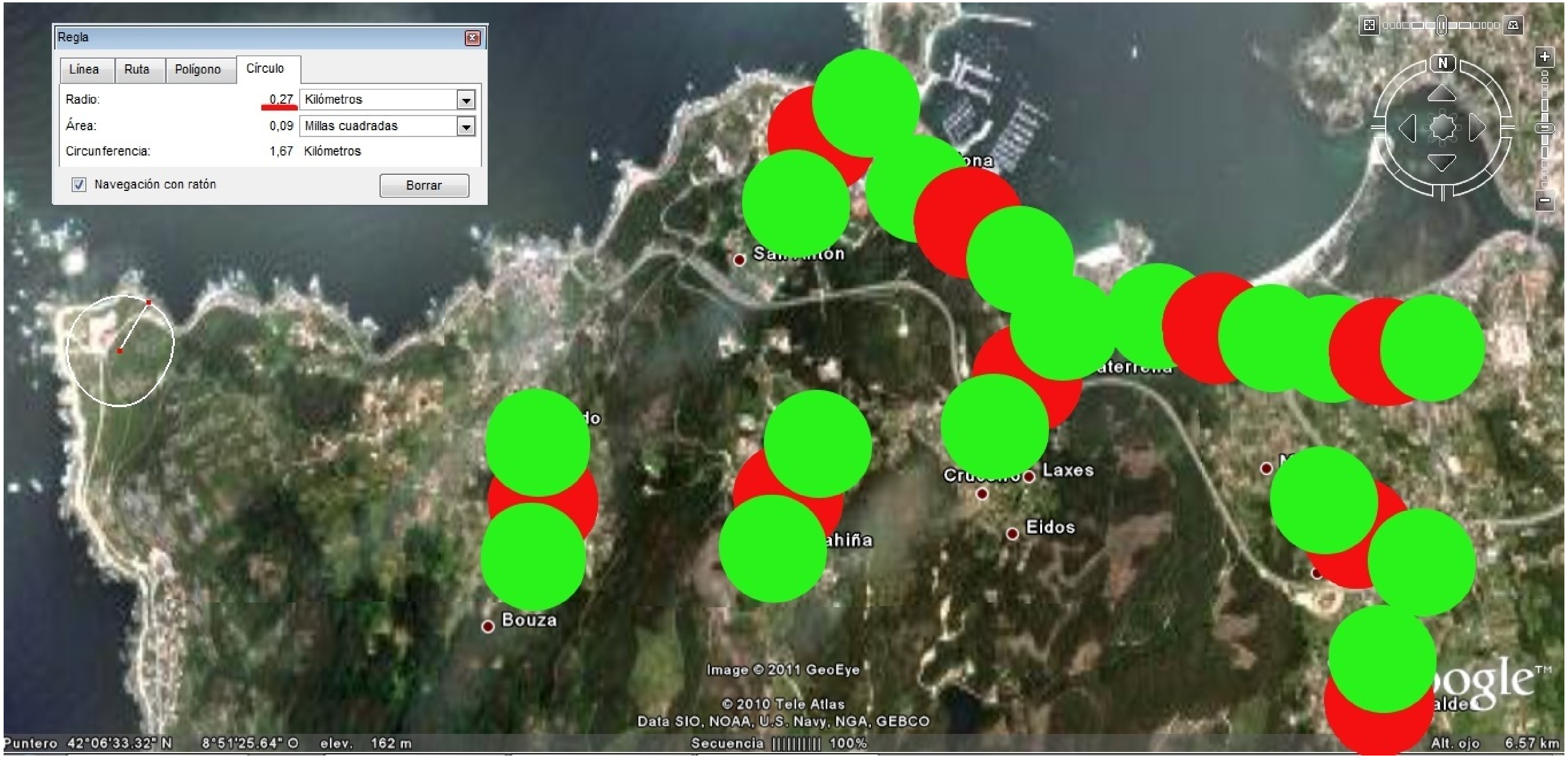



Cada AP tiene dos antenas omnidireccionales. Una de ellas se utilizará para enlazar los APs y la otra para dar cobertura a los usuarios.

# COLOCACIÓN DE LOS APs

Con el programa Google Earth Pro® y la herramienta “CÍRCULO” podemos determinar el radio de los mismos y disponerlos en el camino. Seleccionamos un radio de 270 m.

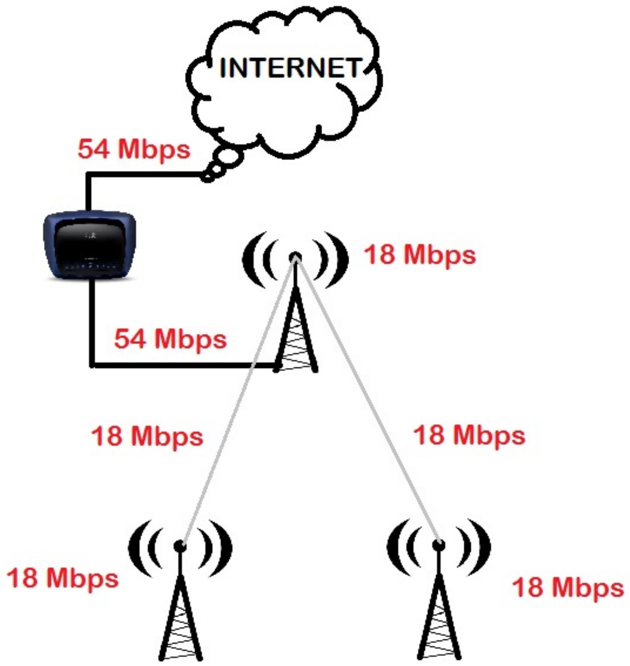
En el esquema, los círculos rojos corresponden a AP conectados a Internet mediante DSL y los verdes a AP configurados como bridge.


Regla
Línea
Ruta
Polígono
Círculo
Radio: 0,27 Kilómetros
Área: 0,09 Millas cuadradas
Circunferencia: 1,67 Kilómetros
Navegación con ratón
Borrar
Laxes
Eidos
Bouza
Image © 2011 GeoEye
© 2010 Tele Atlas
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Puntero 42°06'33.32" N 8°51'25.64" O elev. 162 m
Secuencia 100%
Alt. ojo 6.57 km

# CÁLCULO DEL RENDIMIENTO

Cada AP tiene que ser capaz de soportar el tráfico de 3 APs: él mismo y 2 bridge.

En este caso, 3x20=60Mbps, lo que excede la velocidad máxima del BreezeACCESS Wi$^2$. Sin embargo, esto sólo ocurrirá en casos extremos y, dado el caso, se reducirá ligeramente la velocidad ofrecida a cada usuario.



# 6. ESTUDIO ECONÓMICO

Vemos en la tabla el precio de los dispositivos necesarios.

| Dispositivo | Precio | Cantidad | Precio total |
|---|---|---|---|
| Alvarion® $Wi^2$ | 1700€ | 26 | 44.200€ |
| LMR-900 cable | 13.85€/m | 135 | 1.869’75€ |
| Linksys E3000 | 134€ | 9 | 1206€ |

El precio total será:

$$44200 + 1869'75 + 1206 = 47.275'75€$$

En cuanto a la mano de obra:

| Instalación | Horas | Precio por hora | Número de instalaciones | Total |
|---|---|---|---|---|
| Alvarion® BreezeACCESS $Wi^2$ | 6 | 12€ | 26 | $6 \times 12 \times 26 = 1872€$ |
| Cable deployment | 12 | 12€ | 1 | $12 \times 12 = 144€$ |

El precio total es:

$$1872 + 144 = 2016€$$

Debemos calcular el precio de los alquileres

| **Concepto** | **Cantidad** | **€/mes** | **Total/mes** |
|---|---|---|---|
| Colocación de las antenas en las azoteas de los edificios. | 25 | 800 | $25 \times 800 = 20000€$ |
| ISP | 9 | 40 | $9 \times 40 = 360$ |

Nuestro provedor ISP será Telefónica, el proveedor principal en Baiona y en España.

El precio total de los alquileres es:

$$20000 + 360 = 20.360€ / month$$

Asumiremos un period de amortización de 5 años o, lo que es lo mismo, 60 meses.

$$\frac{47275'75 + 2016}{60} = 829'0291€$$

$$829'03 + 20360 = 21189'03€$$

El precio amortizado de la red es de 21.189’03€ al mes.

# 7. IMPACTO MEDIOAMBIENTAL

## ANÁLISIS ESTÉTICO

En virtud del artículo 12 de la Directiva 2002/21/CE del Parlamento Europeo y el Comité, de 7 de marzo de 2002 sobre un marco común regulador de redes y comunicaciones electrónicas: “el uso compartido de recursos puede ser aprovechable por ordenación territorial, salud pública o razones medioambientales”.

El Real Decreto/Ley 1/1998 sobre las infraestructuras comunes de telecomunicaciones define la necesidad de compartir redes existentes, promoviendo la colocación compartida para minimizar el impacto visual.

Además, en aquellas zonas construidas recientemente donde se ha aplicado la Ley 38/1999 de 5 de noviembre, de ordenación y edificación, se establece la responsabilidad de la Corporación Municipal de que los edificios tengan infraestructura para Telecomunicaciones.

## WI-FI Y CAMPOS ELECTROMAGNÉTICOS

La exposición a los Campos Electromagnéticos está regulada por el RD-Ley 1006/2001 de 18 de septiembre. En este Decreto se aprueba la regulación que establece condiciones de protección del dominio público de radio, restricciones a emisiones radio y protección sanitaria frente a esas emisiones de radio.

Calcularemos la distancia de seguridad:

$$Safety\_distance = \sqrt{\frac{M \times PIRE}{4 \times \pi \times S\max}}$$

M es el factor de reflexión. Usaremos 4, el peor caso (reflexión total).

PIRE será 100mW, el equivalente a 20dB.

Smax es la densidad de potencia máxima. Para dispositivos que emiten entre 2 y 300 Ghz, es 10W/m$^2$.

$$\sqrt{\frac{4\times 0'001}{4\times \pi \times 10}} = \sqrt{\frac{0'004}{125'663}} = 0.0056m$$

No hay riesgo para la salud, ya que la distancia de seguridad son 5.6 cm.

# 8. CONCLUSIONES

En este PFC hemos demostrado que el desarrollo de una red inalámbrica de área local en un área urbana es totalmente posible. Sin embargo, cabe destacar que a medida que aumenta el tamaño de la ciudad, las complicaciones de instalación y despliegue también aumentan.

Nuestra red se basa en tecnologías inalámbricas totalmente implementadas hoy en día, haciendo el acceso a Internet posible para todo el mundo.

Internet es ocio, comunicación, información y soluciones para trabajadores.

Hemos tenido éxito encontrando un buen balance entre el servicio ofrecido y el coste de la red. Esperamos que todos los usuarios queden satisfechos con la velocidad ofrecida. Todo el esfuerzo de este trabajo se centra en el usuario final que aprovecharía esta iniciativa.

Gracias a las tecnologías actuales es posible implementar una red de esta magnitud. Hace algunos años no hubiera sido beneficioso debido al enorme coste que hubiera supuesto.

En cuanto al coste, las cantidades obtenidas resultan permisibles para las características ofrecidas.